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Reconstruction of the Electric System of the University of Illinois

Electrical Engineer

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RECONSTRUCTION OF THE ELECTRIC SYSTEM

OF

THE UNIVERSITY OF ILLINOIS

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BY

ARTHUR CASSON HOBBLE

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THESIS

Submitted in Partial Fulfillment of the Requirements for the

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Arthur Casson Hobble

ENTITLED Reconstruction of the Electric System of the University of Illinois

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Electrical Engineer

In Charge of Major Work

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INTRODUCTION.

This thesis is really a resume, or an appendix, to the B. S. theses on the same subject submitted by Messrs. J. H. Truman, J. K. Burns, E. E. Boon and H. A. Brown, senior Electrical Engineering students of the University of Illinois, 1910-11. The thesis of Messrs. Truman and Burns deals with the electric power plant, while that of Messrs. Boon and Brown treats of the system of electric distribution. To any one not familiar with the system of generation and distribution of electrical energy at the University of Illinois, it is recommended that the above montioned theses be studied before reading the following summary report.

Plans for the reconstruction of the generating plant and distribution systems are already being prepared by the Department of Electrical Engineering, under the supervision of Prof. F. J. Berg, head of the department, and Prof. J. M. Bryant. The building for the new power plant is completed and it is expected that the complete new and reconstructed generating equipment will be in operation next fall.

The object of the following report is to emphasize the bad features of the present system of power and lighting generation and distribution and to submit recommendations for overcoming these defects and otherwise improving the whole system with the least outlay or expenditure.

NOTES ON THE RECONSTRUCTION OF THE ELECTRIC POWER AND LIGHTING SYSTEM OF THE UNIVERSITY OF ILLINOIS.

I.

GENERATING PLANT - RECONSTRUCTION.

1. Location: The generating station is not located at, or even near the center of distribution. The University buildings are for the most part distributed over a rectangular area, the length of which is about 1¼ miles and the width averages about 1/8th mile. The longest distribution feeder is 3600 feet. The generating plant is well located however as regards handling of fuel and drainage.
2. Provision for Future Extension of the new power plant building and equipment is ample.
3. Choice of Fuel and Method of Handling: The fact that steam heating consumes approximately 70% of the necessary coal supply during the whole year fizes the choice of fuel: hence a cheap grade of coal, costing approximately $1.15 per ton delivered from the nearby coal fields is used. The method of handling the coal supply has been amply described by Messrs. Truman and Burns in their thesis. It appears that a large quantity of coal[1] is lost annually due to "spontaneous combustion" of coal in the bunkers as well as that stored out in the open on the level ground. If it is necessary to store a considerable supply of coal out in the open, a large pit or tank which can be easily flooded, should be provided. The grade of coal used by the University of Illinois should not be stored in inside bunkers in a wet condition as it is very like-

1. "Spontaneous Combustion of Coal with special reference to bituminous coals of the Illinois type", by S. W. Parr and F. W. Kressman, University of Illinois, Bulletin No. 46, December 19, 1910.

ly to fire. A considerable saving will be effected if this precaution is taken.

4. Boilers and Auxilliaries: Approximately 500 H.P. boiler capacity is at present required to meet the maximum load demand. The remaining 1330 boiler H.P. being required to supply the maximum demand for steam heating. With the rapid increase in the number of University buildings with a corresponding increased deamnd for electrical energy and steam heating, the boiler plant has been increased by the installation of a battery of 2-500 H.P. water tube boilers in the new power plant. These two boilers will be required entirely for the electric plant in the course of the next two years.

It is seen that the present ratio of boiler and auxilliaries equipment required for electrical energy to that required for steam heating is 500/1830, i.e., approximately 37% of the total investment for boilers, pumps, feed water heaters, steam piping, etc. is chargeable to the electric plant.

The writer believes that it is a mistake to use steam driven auxilliaries in this plant (with the one exception of a steam driven exciter unit) where economy should be striven for even though exhaust steam is used for heating. Electric motor driven auxilliaries will effect a saving in cost of steam piping as well as heat losses.

5. Choice of Prime Movers and Generators: The low price of coal, limited supply of water, and the fact that a vastly larger proportion of the steam generated is used for heating than for electric power generation, reduces the choice of prime movers to two types: namely (1) non-condensing steam turbines, (2) simple non-condensing

reciprocating engines. There is not much to choose between these two types but the writer gives a slight preference to the steam turbine for the following reasons: (1) lower first cost, (2) smaller floor space, (3) better speed regulation for parallel operation, (4) high speed desirable for small generator units, (5) higher all-round efficiency from no load to very heavy overloads. The latter is a very important consideration in the University of Illinois power plant which has a connected load of more than 1000 K.W. with a normal generator capacity of less than 300 K.W.

During peak load periods in the winter the reciprocating engines in the old power plant have been unable to carry the load, making it necessary to "cut out" one or more feeder circuits for a short time. This overloading which is due to an overlapping of the day motor load and evening lighting load together with high back pressure in steam heating mains, has also been productive of poor voltage regulation and otherwise inefficient operation.

The writer believes that a mistake was made in the choice of the 125 K.V.A. Ball engine unit in the new power house not only for the aforementioned reasons but it is a great mistake to install such a variety of units, both prime movers and generators, as we have in our University power plant. A Westinghouse engine, an Ide engine, a Ball engine and a Curtis turbine is not a combination of prime movers that will insure low maintenance charges and high plant efficiency and reliability. The same applies to the generator installation which includes Westinghouse revolving armature, Westinghouse revolving field, Allis Chalmers revolving field and General Electric turbo-generators, all having different speeds, different number of poles and no doubt different wave

shapes, as well as having different types of D.C. exciters of different voltage.

6. Rearrangement of Generating Units: This is being accomplished at the present time and should be completed by next fall. The problem is,- with the present equipment, to effect the most economical and efficient arrangement of generating units and feeder circuits keeping in view the ultimate probability of completely changing the present 2-phase 440 volt system to a 3-phase 2300 volt system. It is immediately apparent, without making accurate estimates, that to change at once the whole of the present system of distribution from 2-phase to 3-phase would entail a heavy and needless expenditure.

During the next two or three years several new buildings will be erected, one or more near the power plant and probably several on the south campus. For the former, the 440 volt 2-phase distribution is inadequate, but for the latter there is no question that 2300 volt 3-phase feeders with step down transformers is advisable. The latter policy has already been adopted for the new Lincoln Hall with its 1200 incandescent lamps and a probable motor load of from 35 H.P. to 50 H.P. A sufficient capacity of 2300/220-110 volt transformers has been installed at Lincoln Hall as a secondary center of distribution for the Auditorium and Woman's Building as well.

As previously stated, the longest 2-phase 440 volt feeder (3600 feet) supplies a mixed power and lighting load at the Farm Buildings aggregating 80 K.W. This load may be expected to double in the next three years. There is no question as to the advisability of changing this feeder to 2300 volts, 3-phase.

With these changes practically certain the 3-phase load will be as tabulated below.

		Kilowatts		K.W.
	Building	Lights	Motors	Total
	Lincoln Hall	67	35	102
Group 1	Auditorium	60	0	60
	Woman's Building	21	0	21
Group 2 -	Farm Buildings	17.5	65	82.5
	Totals	165.5	100	265.5

The total three-phase connected load will be, therefore, approximately 265 K.W. The writer estimates an increase during the next three years of 50% for Group 1 and 100% for Group 2, making a total future connected 3-phase load of nearly 440 K.W. Since the average ratio of maximum peak load to connected load is about 30%, the required three-phase generator capacity for this load alone would approximate 150 K.V.A.

The total remaining two-phase connected load is about 1000 K.W. This means a maximum load of approximately 300 K.W. which is beyond the capacity of the two two-phase generating units with a combined output of 245 K.V.A. Of the latter, the new Allis-Chalmers 125 K.V.A. unit is already installed in the new power house and the 120 K.V.A. Westinghouse unit,now in operation in the old power plant, is soon to be shifted over to the new power house. This completes the power house units aggregating 370 K.V.A. but loaded considerably above their normal capacity. It will be seen from the load curves of typical feeders, as well as those of the whole power plant load, that the maximum peak load of the year occurs at about 5 P. M. on winter evenings when the day motor

load and evening lighting load overlap. At this time the generating units must be capable of carrying an overload of from 25% to 50% for a very short period but this is next to impossible with the prime movers working against a back pressure of 20 lbs. or more in the steam heating mains. This overload condition may be relieved to some extent by arranging for the exhaust of one or more of the engines or the turbine to atmosphere during the overload period.

The writer believes that all future extensions of both generating units and power and lighting distribution should be 3-phase 2300 volts with step-down transformers at the end of feeders. The next extension in the new power plant after the installation of the new two-phase switchboard should be the installation of a second 3-phase Curtis turbo-generator unit the size of which will of course depend upon the present excess load and upon probable future demand. A 300 K.V.A. unit will be necessary, provided the old 120 K.V.A. Westinghouse unit,which has a low efficiency, is not used. Such a course will however depend upon new extensions on the south campus requiring three-phase distribution, and the rate of changing over ultimately from two-phase to three-phase for distribution to all the other buildings south of Green Street, which the writer recommends. Should the two-phase demand still require the old 120 K.V.A. Westinghouse unit, the new proposed 300 K.V.A. turbo-generator should be installed just west of the 125 K.V.A. turbo-generator unit.

7. Switchboards, General Arrangement: There is at present in the new power house a 3-phase switchboard for the 125 K.V.A. turbo-generator unit, comprising, in the following order from west to east: 2-

2300 volt feeder panels, one 2300 volt generator panel, and one 125 volt exciter panel. At the present time one of the feeder panels is used to connect with the old two-phase plant through 2300/440 volt Scott connected transformers. This panel will continue to be used for the Electrical Laboratory feeder. The second feeder panel will be used for 2300 volt 3-phase distribution to Lincoln Hall. A third 2300 volt 3-phase panel will be required for a new feeder to the Farm Buildings unless the latter are supplied from the Lincoln Hall feeder. This takes care of all proposed 3-phase feeder extensions at the present time. The writer considers it advisable to add another panel for direct current distribution, i.e., a motor-generator panel. As the demand for further three-phase distribution continues, other feeder panels may be added to the west end of the board.

The new 2-phase, 440 volt switchboard will be installed to the east of the present 3-phase switchboard. The writer would recommend that it be planned and installed keeping in view, as previously stated, the installation of one or more 3-phase units in the near future, one of which may displace the old 120 K.V.A. Westinghouse 2-phase unit. Provision should be made for installing a new three-phase generator panel and the aforementioned motor-generator panel between the exciting three-phase generator panel and the two three-phase feeder panels. Next to the east adjacent to the existing exciter panel should be a Tirrill regulator panel, then in regular order should come a 440/2300 volt transformer, or bus-tie, panel, one 440 volt, 2-phase generator panel for the 120 K.V.A. Westinghouse unit, one 440 volt, 2-phase generator panel for the 125 K.V.A. Allis-Chalmers unit and two 440 volt 2-phase

feeder panels. The reason for having two 440 volt 2-phase feeder panels will be apparent when the number and arrangement of feeders is discussed. There are several particular features of the above recommended switchboard arrangement which require more detailed consideration. (See Drawing I).

(a) Transformer Panel: Parallel operation of all the generating units requires the connecting together of the 3-phase 2300 volt buses with the 2-phase 440 volt buses through 2300/440 volt Scott connected transformers. Since the normal capacity of the two-phase generators is 245 K.V.A., this should be effected with one 250 K.W. transformer or 2 - 125 K.W. transformers. A 2300 volt oil switch must be provided on the high tension side of these bus-tie transformers not only for the purpose of breaking the circuit, but also for synchronizing the 2-phase and 3-phase buses. A 4-pole single throw knife switch is considered ample for the low tension side of the transformers. These two switches - the 2300 volt oil switch and the 440 volt knife switch - should be mounted on a separate panel, previously mentioned, which should be provided with two ammeters, one connected in each phase on the 2-phase 440 volt side of the transformers. The synchroscope should be mounted on a swivel on top of the transformer panel or on a swinging bracket at the east end of the switchboard. A 440/110 volt potential transformer must be provided for synchronizing though this may be supplied from the old switchboard.

(b) Exciter Panel: At the present time each generator is provided with a separate exciter. These exciters vary widely in type and speed and somewhat in voltage. The individual exciters for the 2-phase generators are belt driven. The exciter for the 125

K.V.A. turbo-generator is mounted on the same shaft with the turbo-generator and is wired to the one exciter panel. For satisfactory parallel operation of the generator units and proper voltage regulation it is necessary to have one common exciter, independent of the larger generating units. This should be a 25 K.W. 125 volt shunt wound generator direct connected to a 50 H.P. simple vertical marine type reciprocating engine. The exciter should be designed especially for use in connection with the Tirrill regulator. A 25 K.W. exciter is specified in order to provide excitation for the proposed new 300 K.W. unit in addition to the existing units. The existing exciter panel on the three-phase switchboard is sufficient also for the proposed 25 K.W. exciter with the addition of a double-pole single-throw main switch and a single-pole single-throw field switch for the latter as well as a few other additions specified later. With the two main switches, one for each exciter, they should be wired for parallel operation of the exciters.

(c) Motor-Generator Panel: Several buildings require direct current in small quantities for projecting lanterns and other special work. To meet this demand, three schemes are possible,- (1) the installation of small motor-generator sets in each building requiring direct current; (2) the installation of one or more motor-generator sets at secondary centers of distribution; (3) the installation of one motor-generator set in the power plant, of sufficient capacity to meet the whole demand. The latter alternative is believed to be the best since it affords complete control and superintendence by the power plant switchboard attendant, besides making it possible for the latter to regulate the power factor of

the system to a certain extent, as explained later. The direct current distribution should be 250/125 volts 3-wire. The writer recommends a synchronous motor-generator set of not less than 50 K.W. capacity and if the direct current requirements of the Electrical Laboratory are to be supplied from the new power plant, a still larger set should be installed; though it may be more advisable for the laboratory to have its own motor-generator set located in the Laboratory. The synchronous motor is advocated, as it may be operated at all times, loaded or unloaded for power factor regulation. A 2080 or 2300 volt motor with starting compensation is recommended.

(d) Voltage Regulator Panel: The voltage regulation of the system is very poor, especially during the winter evenings when the load is heavy and numerous induction motors are running, many of them very lightly loaded. Better voltage regulation will be secured by the installation of one Tirrill regulator in connection with the exciters and one in connection with the synchronous motor-generator set for power factor regulation, though the latter is not absolutely essential and is not called for in the specifications or shown on the switchboard layout. The exciter regulator should have two or more relays for operating two or more exciters in parallel and should be installed adjacent to the exciter panel for convenience in switching in or out of service.

The original plan was to connect the series transformer of the voltage regulator in one phase of the three-phase feeder circuit to Lincoln Hall, i.e., in the phase which will carry the heaviest lighting load. The writer objects to this scheme for the reason that good regulation would be obtained only on that partic-

ular feeder. The only feasible plan with the present mixed two-phase and three-phase distribution is to connect the series transformer directly in the power plant buses. This will give uniform voltage regulation on all feeders.

(e) Street Lighting Panel: A street lighting panel will be necessary if it is decided to install the series tungsten system using a constant current transformer, or even the multiple tungsten system, for lighting the campus, if control at the power house is desired. This will be more fully discussed under "Systems of Distribution".

8. Summary of Switchboard Arrangement: The final complete arrangement of the switch board, including slight changes or reconstruction of the present three-phase switchboard in the new power house, is recommended as follows,- the panels being listed from west to east. (See Drawing No. I).

Two 2300 volt, 3-phase feeder panels, each of which should be equipped as follows; one 2300 volt, 100 ampere, 3-phase oil switch with automatic trip and time limit overload relays, one A.C. integrating wattmeter, three A.C. ammeters, two series transformers. Two potential transformers of sufficient capacity will suffice for the integrating wattmeters on all three feeder panels. The addition of three other like panels in the future should be kept in mind.

One motor-generator panel for a 2300 volt, 3-phase synchronous motor direct connected to a 50 K.W. 250/125 volt D.C. generator. Panel to be equipped with one 2300 volt, 25 ampere, 3-phase oil switch; one 250 volt, T.P.S.T. 200 ampere D.C. knife switch; one 125 volt, 10 ampere D.P.S.T. direct current motor field

switch; one generator field rheostat, one meter with series and potential trnasformers for same, one Tirrill regulator for power factor regulation to be mounted on bracket at side of panel.

Two 2300 volt, 3-phase generator panels, each of which should be equipped as follows; one 2300 volt, 100 ampere, 3-phase oil switch for the proposed new 300 K.W. unit, one D.P.S.T. generator field switch with discharge resistance, one synchronizing plug and receptacle, one generator field rheostat, one A.C. voltmeter, one A.C. ammeter, one A.C. indicating wattmeter, series and potential transformers.

One D.C. 125 volt exciter panel,- to be equipped as follows; one 125 volt, 200 ampere, D.P.S.T. knife switch, one 125 volt, 40 amperem D.P.S.T. knife switch, one S.P.S.T. 10 ampere field switch, two field rheostats, one D.C. voltmeter, one A.C. station voltmeter, one D.C. ammeter, one 6-point potential receptacle with 4-point plug.

One Tirrill voltage regulator panel,- to be equipped with a two relay regulator and accessories for two 125 volt exciters. Regulator to be operated from the three-phase buses.

One 440/2300 volt transformer (bus-tie) panel,- to be equipped with one 2300 volt, 100 ampere, 3-phase oil switch, one 4-pole S.T. 440 volt, 300 ampere knife switch, two ammeters for 2-phase side, one 2300/110 synchronizing potential transformer, one synchronizing plug and receptacle.

Two 440 volt, 2-phase generator panels, each to be equipped as follows; one 440 volt, 150 ampere, 2-phase oil switch, one 125 volt, 50 ampere D.P.S.T. generator field switch with discharge resistance, one generator field rheostat, one synchronizing

plug and receptacle, one voltmeter plug and receptacle, one A.C. voltmeter, two A.C. ammeters, one indicating wattmeter, series and potential transformers.

One 440 volt, 2-phase feeder panel,- to be equipped as follows; one 440 volt, 250 ampere, 2-phase oil switch with automatic trip and time limit overload relays, one A.C. integrating wattmeter, two A.C. ammeters, series and potential transformers. A second 2-phase feeder panel may be required for the Electrical Laboratory and is shown on the switchboard drawing.

The synchronous indicator, or synchroscope, may be located on a swinging bracket at the east end of the switchboard or centrally on top of the transformer, or the exciter panel.

9. Future Considerations: If the time comes when all feeder distribution will be three-phase, 2300 volts, the 2-phase 440 volt feeder panels should be shifted over to the west end of the switchboard and converted into three-phase panels. This will finally leave all generator panels at one end of the switchboard and feeder panels at the other end, which arrangement is most satisfactory.

The aim in the power house should be to simplify and standardize. This cannot be effected by placing orders for generator units, switchboards and other electrical equipment with several manufacturing companies. Such a great diversity of power plant equipment as exists in the University of Illinois power plant not only complicates and causes inefficient and unsatisfactory operation but promotes heavy maintenance charges. The same applies to the boiler house equipment.

One important feature which has been overlooked in the past with regard to choosing prime movers of sufficient capacity,

is the fact that during the winter months when the peak load is heaviest, the steam heating load is also at its maximum; thus necessitating the prime movers to operate against a back pressure of 20 lb. or more. At such times they will not carry the full load generator capacity. In future a liberal allowance in the capacity of prime movers must be given.

II.

SYSTEMS OF DISTRIBUTION - RECONSTRUCTION.

10. Present Conditions: The writer will not dwell in detail upon the system of power and lighting distribution prevailing in each building or group of buildings, as this has been featured to a great extent in the thesis of Messrs. Boon and Brown.

In general, it may be stated that there are almost as many feeders as there are buildings of any size; thus necessitating a transformer or group of transformers for each building - a most uneconomical condition. Some buildings have 440/220 volts for lighting, other 220/110 volts; some utilize both phases of each two-phase circuit, others only one phase. Some buildings are supplied by auto-transformers, others by ordinary step-down transformers, and there are six or more different types or makes of transformers used. Many transformers are located in dark places where they are difficult to inspect and are rarely inspected, and where the fire risk is great. The low tension side of some 440 volt transformers is grounded and on others it is not.

The wiring of many of the buildings, particularly the older buildings, is very defective. The writer is not aware even that the wiring installations in the more recently constructed

buildings are thoroughly inspected during installation and tested after completion.

The interior illumination of our University buildings could be made a subject for much adverse criticism. Little or no attention has been given to choice of illuminants or their location with respect to efficient light distribution. In some buildings, motors of appreciable size are operated from lighting circuits; in fact lights and motors have been installed in various buildings without consulting the Supervising Architect, the Electrical Department, or the Superintendent of Buildings and Grounds.

In the tunnels, which were constructed primarily for steam heating mains, we have a mixture of lead covered cables and wires without lead covering. The feeder cables are placed directly above the steam pipes where they acquire the maximum heat radiation from the latter.

As a typical example of motor installations in some of the buildings, the writer would call attention to the Agricultural Building which has the following 440 volt 2-phase motors.

One 5 H.P. belted to a line shaft operating a large churn. This motor is also belted to a counter shaft which operates a small churn, a cream separator, Pasteurizer and one or two other small pieces of apparatus requiring not more than 1.5 H.P. Most of the time this 5 H.P. motor is required to do about 1 H.P. duty.

One 5 H.P. motor operating meat chopper, hay cutter and grinding mill. It is used less than one-fourth of the time and is much underloaded. The writer estimates that a 2 H.P. motor will operate these machines.

One 5 H.P. motor operating two grinders - mostly for grinding sand. This motor is in use only a few hours every day, or every few days. A 2 H.P. motor is sufficient.

One 5 H.P. motor operating two grinders in the Agronomy Preparation Room. It is very seldom used. A 2 H.P. motor is sufficient.

This affords one explanation for the large ratio of actual metered load to connected load, which is about 1/30. It also explains the very low power factor - 0.75 to 0.80 during the day, and much needless and careless expenditure of money which is not paying interest on the investment. It also reveals the urgent need of inaugurating a system which shall require that all demands for additional light and power in the various buildings of the University shall first be investigated by a responsible authority in consultation with the Electrical Department to the effect that proper lamps, motors and other light and power apparatus may be installed, suitable for the purpose for which they are intended. The writer understands, however, that this matter is being fully considered by the Supervising Architect under recommendations from the Electrical Department.

11. Standardization of Interior Wiring: The system of interior wiring for individual buildings should be 220/110 volt, 3-wire for lighting and 220 volts, 2-phase or 3-phase for motors. Direct current distribution, where necessary, should be 220/110 volts 3-wire.

The lighting circuits should be entirely separate from the power circuits in each building, though supplied from the low tension side of the same transformers.

In the future, no installation of wiring let out by con-

tract should be accepted without thorough inspection and testing at double potential and for grounds by some competent employee connected with the Electrical Department.

12. Interior Illumination: At least 75% of the interior lighting is at present accomplished with inefficient and inferior types of incandescent lamps, most of which are the old 16 c.p. 56-60 watt carbon filament type. The lighting load could be reduced about 25% by using 40 watt metallized filament lamps and a large number of lamps could well be replaced by tungsten units, thus further reducing the lighting load. The lighting plan of buildings should be drawn up by one who has a proper understanding of the requirements and who may be depended upon to choose the most efficient type of illuminant and locate the same to the best advantage in view of the requirements.

13. Character and Distribution of Load: The distribution of connected load in the various buildings is given in the accompanying table (see Table I). The incandescent lamps are rated at 56 watts per lamp. The total connected load south of Green Street is approximately 684 K.W., while that north of Green Street is about 700 K.W. It will be seen from the accompanying diagram that the most congested area is north of Green Street and comparatively near the power plant. This total connected load of some 1380 K.W. could be reduced at least 25% by the installation of efficient lamps and properly rated motors. For instance, the present rated motor load of 39 H.P. in the Agricultural Building could be easily reduced 40%.

The load factor of the whole system is extremely low; the ratio of average load for the year to total connected load be-

ing not more than 10%, whereas the ratio of maximum load to connected load does not exceed 30%.

It will be noticed in Table I that K.W. lighting has been added to H.P. of motors to give total K.W. This has been considered allowable in order to include approximately all distribution losses as it is customary, when transformers are used in connection with motors, to rate the former approximately as many kilowatts as is the rated horse power of the motors.

Since the load demand requires the installation of a new generating unit in the new power house in the very near future and that unit is recommended to be a 3-phase, 2300 volt turbo-generator of 300 K.V.A. capacity, immediate steps should be taken to convert a part of the present 2-phase 440 volt distribution to 3-phase, 2300 volts. It will be advisable to first convert the longest feeders.

14. Number and Arrangement of Feeders: More efficient service and a considerable saving in cost of distribution will be effected by supplying several buildings or a group of buildings from one feeder. Both the number of feeders and number of transformers may be reduced some 60%, thus considerably reducing the distribution losses. The outgoing feeders from the power house may be reduced in number ultimately from 15 to 6 or even less.

The first change recommended is to group Lincoln Hall, the Auditorium and Woman's Building on one 3-phase, 2300 volt feeder with the center of distribution at Lincoln Hall. This has been partly accomplished by the installation of 3-wire 220/110 volt distribution in Lincoln Hall from a group of 3 - 30 K.W. 2300 - 220/110 volt transformers fed by a 3-phase, No. 6 B. & S. underground

cable through the steam tunnel from the power house. Arrangements for supplying the Auditorium and Woman's Building from the low tension side of the transformers in Lincoln Hall should be undertaken as soon as possible. An examination of the accompanying diagram of the University buildings and grounds shows the possibility of extending three-phase distribution from the above mentioned group of buildings to all other buildings, and probable future extensions, between a line drawn east and west through the Observatory to the street car track in line with California and Daniel Streets. All territory between these two lines is designated Block III.

The next immediate change recommended is three-phase distribution to all of the Farm Buildings(1)on both sides of Forestry Road. The length of this feeder would be approximately 3600 ft. to a center of distribution between Burrill Ave. and Wright Street near Forestry Road. An underground feeder will involve considerable expenditure, including not only the actual cost of the lead covered cable but underground conduit construction for a distance of at least 1000 ft. providing the steam tunnel is used from Lincoln Hall or the Auditorium to the power house. The writer seriously objects to the installation of powerand lighting cables, especially 2300 volt cables, in the steam tunnels for reasons previously given and furthermore owing to the danger of serious electrical shocks to men effecting repairs to steam pipes.

Should the cost of complete underground construction be considered too great, the writer recommends the use of the present pole line from the Agricultural Building to Forestry Road, and the installation of a 2300 volt, 3-phase underground cable from the Agricultural Building to the power house. This again involves three

alternatives: (1) the installation of the 2300 volt cable in the steam tunnel which is objectionable and should be only temporary, (2) underground conduit construction down Burrill Ave. as far as Agricultural Building or the Auditorium, joining the pole line near one or the other of these points, (3) a complete temporary overhead line from the power house down Mathews Ave. to the Farm Buildings. If underground conduit construction is out of the question for the present on account of the expense involved, the writer recommends the last alternative, i.e., a neatly constructed temporary pole line with bare wires. The bare copper wires and poles could later be used for the proposed experimental high tension line to be constructed on the farm. The installation of new cables in the steam tunnel means the additional work of pulling them out again in the near future, when conduit construction is undertaken, with the likelihood of seriously damaging them beyond repair. That the growth of the University power and lighting system will sooner or later require modern underground conduit construction is practically certain. This should be kept in mind and carried into execution in the near future.

For the present, therefore, the most immediate and cheapest construction for arranging approximately 265 K. W. of connected load for 3-phase distribution is by pole line construction to the Farm Buildings and an extension of the present 3-phase distribution in Lincoln Hall to the Auditorium and Woman's Building. If extension to the present pole line is considered undesirable, the Farm Buildings may be connected temporarily to the 3-phase, 2300 volt feeder at Lincoln Hall, since an actual load of 150 K. W. on this feeder will not produce more than 2% voltage drop. With not

more than 3% drop, the Agricultural Building could also be supplied from this feeder. This would make a total connected 3-phase load south of Green Street of approximately 345 K. W., though this could easily be reduced to 260 K. W. or even less by the installation of efficient types of lamps and 3-phase 220 motors of proper rating. In the latter event, the Chemistry Building could also be connected temporarily to Lincoln Hall feeder, leaving the remaining buildings to be supplied by a 2-phase, 440 volt feeder.

At all events, the campus south of Green Street may be supplied by two feeders; one 3-phase, 2300 volt feeder supplying the load farthest away from the power house and possibly including the Agricultural Building, and one 2-phase, 440 volt feeder supplying the remaining buildings south of Green Street with the Natural History Building as a temporary center of distribution. This would just about equally load these two feeders. It is recommended however that all buildings south of Green Street be supplied with 3-phase current as early as possible.

North of Green Street there is a congested area near the power plant supplied by seven 2-phase 440 volts feeders, the center of distribution being the present engine room of the old power plant. One 3-phase, 2300 volt feeder connects the old and new plant switchboards through Scott connected transformers. This feeder will be retained for the Electrical Laboratory.

For the present, the seven 2-phase feeders may continue to be fed at 440 volts from the Electrical Laboratory as a secondary center of 440 volt distribution, the latter being connected to the two-phase feeder panel in the new power house temporarily by means of a No. 3 B. & S., 4 conductor, 440 volt cable. The connected load on the latter will be approximately 500 K. W.

The foregoing plan reduces the number of main feeders from 15 to 4 besides concentrating the large and scattered number of transformers, south of Green Street, at two and not possibly more than three centers of distribution.

The grouping recommended, therefore, for immediate reconstruction is as follows.

Feeder-panel, No. 1, 3-phase, 2300 volts, - to supply Farm Buildings, Observatory, Agricultural Building, Auditorium, Lincoln Hall and Woman's Building - connected load, 345 K. W., estimated future load, 500 K. W. - size of conductor in present feeder, No. 6, B. & S. - center of distribution at Lincoln Hall.

Feeder-panel, No. 2, 3-phase, 2300 volt, - to supply Electrical Laboratory - connected load 200 K. W. - estimated future load 300 K. W. - size of conductor in present feeder, No. 6, B. & S. - center of distribution in Electrical Laboratory. A two-phase feeder and feeder panel will also probably be required for the Electrical Laboratory. Further consideration of this is not undertaken here as Prof. J. M. Bryant is more familiar with both the present and future requirements of the Electrical Laboratory and is at present working on the details of electrical distribution for the same.

Feeder panel No. 3, 2-phase, 440 volts, - to supply all other buildings north of Green Street - connected load 500 K. W. - estimated future load 700 K. W. - length of main feeder, 200 ft. - size of conductor reqiured, No. 3, B. &. S. - temporary center of distribution at Electrical Laboratory - future permanent center of distribution to be in new power house.

Feeder panel No. 4, 2-phase, 440 volts, - to supply all

other buildings south of Green Street not mentioned in connection with feeder-panel No. 1 - connected load 335 K. W. - estimated future load 400 K. W. - length of main feeder, 1100 ft. - size of conductor required, 2/0 B. & S. - temporary center of distribution at Natural History Building.

15. Secondary Centers of Distribution: The main feeders from the power plant switchboard should feed a transformer or group of two or more transformers located at secondary centers of distribution. If 3 three-phase transformers are used, they should be connected delta-delta to enable continued operation in case of damage to one of them. The centers of distribution should be located where there is the minimum fire risk and where they are easily accessible for disconnection of low tension interior distribution circuits. Underground conduit construction with large manholes as secondary centers of distribution is the best construction, though expensive.

The writer does not recommend fuses, cutouts or other circuit protective devices on the high tension side of the transformers as experience has shown that these are a constant source of trouble. The distribution circuits from the low tension side should be provided with properly fused cutouts mounted on a simple slate or marble panel board. The circuits should be carefully numbered, named or otherwise designated.

16. Final System of Distribution: The writer believes that the ultimate system of distribution of electric power and lighting for the University of Illinois should be 3-phase, 2300 volt, 60 cycles, using underground conduit construction with lead covered cables for the main feeder distribution, manholes with subway transformers at centers of distribution, and 220/110 volt, 3-wire distribution in

the buildings. The manholes should be located at a sufficient distance from buildings to avoid fire risk and should be of sufficient size to allow for the installation of three single phase transformers of proper capacity, with additional room for installing cables.

The distribution to all buildings south of Green Street should be made 3-phase as soon as possible; whereas the present 2-phase, 440 volt distribution north of Green Street will suffice for some time. Additional reqiurements for two-phase motors in this congested area should be met by the old two-phase motors on the south campus, the latter being replaced by efficient three-phase motors of proper rating.

The writer believes that three or possibly four 3-phase, 2300 volt feeders will be ultimately required for the distribution south of Green Street. The arrangement of these feeders with approximate location of manholes, or centers of distribution, and sub-feeders is shown on Drawing No. II. The whole area of distribution is shown divided into five blocks or sections, each feeder supplying one block. At some future time when other buildings are erected a feeder will probably be required for Block IV.

17. Street and Campus Lighting: It is needless to state that the present inefficient 9 ampere series open-arc system should be displaced as soon as possible with something better; in fact the writer advocates its immediate dissolution before anything else is done, as it is more a waste of good energy than anything else, in its present condition.

The writer recommends the ultimate installation of the efficient series tungsten system for campus lighting. This system

is peculiarly adapted for the campus on account of the number of shade trees making the use of arc lamps for the most part inadvisable. As overhead distribution is considered undesirable, the more costly underground distribution using suitable ornamental lighting standards is advocated. It is well to point out, however, that the extra cost of the underground system for campus lighting will not amount to as much as a separate estimate would indicate, since the majority of the campus lights would be located on Burrill Ave.; hence the underground conduit systems for both interior and street lighting would be estimated in one lump sum.

Until such time as funds may be secured for the installation of the conduit system for both interior and street lighting, the writer recommends the immediate installation of suitable entrance lights to all University buildings. At the present time many of the buildings have no exterior entrance lights, some have one kind and some have another kind,- a lack and a diversity which is inexcusable. Suitable ornamental entrance lights of high candle power provided with efficient light diffusing globes will not only aid one in locating the entrances to the various buildings but will provide a fairly effective and a very inexpensive system of campus lighting.

TABLE I.

Distribution of Load.

A. South of Green Street.

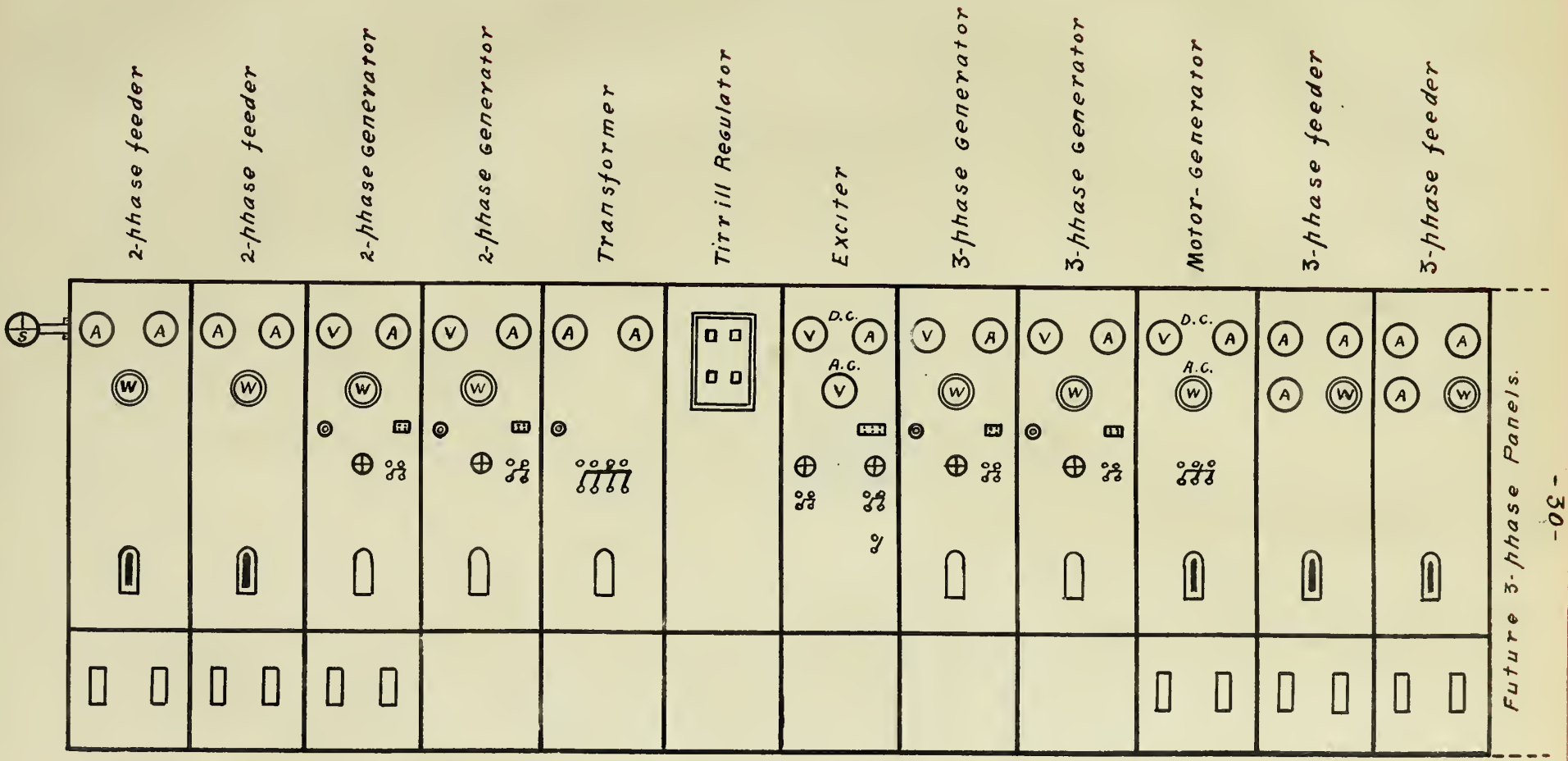
	Lights.		Motors.	Total.	Distance from Power house in feet.
	No.	K.W.	H.P.	K.W.	
1. Farm Buildings	315	17.5	65.0	82.5	3600
2. Observatory	35	2.0	0.25	2.25	2600
3. Auditorium	1172	59.5	-----	59.5	2500
4. #Lincoln Hall	1200	67.0	35.0	102.0	2500
5. Woman's Building	381	21.0	-----	21.0	2200
6. Agriculture	725	41.0	39.0	80.0	1900
7. Chemistry	595	33.0	35.0	68.0	1400
8. Main Hall	518	29.0	2.0	31.0	1400
9. Library	481	27.0	20.0	47.0	1700
10. Y.M.C.A.	700	39.0	-----	39.0	1900
11. Law	156	8.5	-----	8.5	1200
12. Natural History	1535	86.0	57.0	143.0	1100
Total		430.5	253.25	683.75	

B. North of Green Street.

13. Physics Building	1800	101.0	47.0	148.0	580
14. Engineering Hall	695	39.0	----	39.0	580
15. President's House	79	4.5	----	4.5	1000
16. T. & A. M. Laboratory	115	6.5	35.0	41.5	500
17. Electrical Laboratory	343	19.0	200.0	219.0	200
18. M. E. Laboratory	168	9.5	35.0	44.5	50
18. Power Plant Buildings	50	3.0	75.0	78.0	---
19. Metal Shop	118	6.5	55.0	61.5	200
20. Wood Shop	170	9.5	22.5	32.0	500
21. Armory	300	17.0	----	17.0	825
22. Gymnasium	252	14.0	----	14.0	1000
23. Green House	33	2.0	----	2.0	350
Total		231.5	469.5	701.0	

#. Not being supplied, as installation is not completed.

The numbers of the buildings from 1 to 23 refer to the numbers on Drawing II, showing the layout of buildings and grounds and proposed system of electrical distribution.



I.

Proposed Switchboard Reconstruction.

- Time limit overload relays.
- Automatic oil-switch.
- Non-automatic oil-switch.
- Field rheostat.
- Synchronizing receptacle.
- (A) Ammeter.
- (V) Voltmeter.
- (W) Wattmeter.
- 250-125 D.C. switch.
- Potential receptacles
- Exciter field switch.
- Exciter main switch.
- Generator field switch.
- 2-phase, 440 volt, trans. switch.

---- Existing 2-phase 440 volt pole line.

---- Possible 3-phase 2300 volt pole line.

——— Proposed 2300 volt underground feeders.

——— 230-115 volt distribution network.

○ ○ Ordinary manholes for pulling in cables.

( ) 2300/230-115 volt underground secondary centers of distribution. ( ) Temporary.

II.

BUILDINGS AND GROUNDS. PROPOSED DISTRIBUTION SYSTEM.

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